

DESIGN AND PERFORMANCE OPTIMISATION OF THE STEERING SYSTEM OF A VEHICLE

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ABSTRACT

The steering system is the most vital element in any automobile. It helps the driver to keep control on the manoeuvring of the vehicle and it also provides stability to it. The major problems during design in Steering System is, to control bump steer, camber changes during cornering and slipping of tires. To minimise these problems, effect on Steering System, a proper designing procedure is followed and analysed in Lotus SHARK v5.01. Through that, the performance of Steering System is substantially improved. This study describes the design and optimizing of the steering system, of an ATV (All Terrain Vehicle).

KEYWORDS: Ackermann Geometry, Turning Radius, Wheel Alignment Parameters, Cornering Forces, Roll Steer, Bump Steer & Neutral Steer Point

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INTRODUCTION

As Steering system is one of the controlling systems of the vehicle, it provides the direction and dynamic stability to the vehicle, along with the suspension system. It helps the vehicle to negotiate the sharp turns.

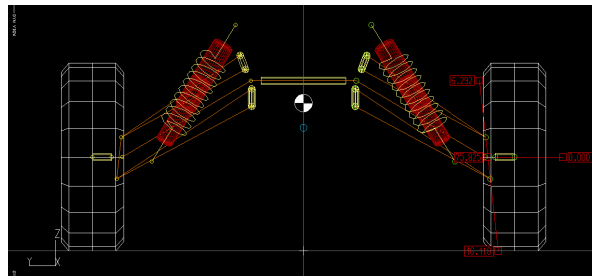


Figure 1: Plotting of Hard Points Steering System in Lotus Shark v5.01

During the designing of the steering system, based on the function and usage, the following design considerations are followed:

- Pure rolling motion of tires during cornering
- Minimum bump or roll steer.
- Reversibility in steering.
- Compatibility with the Suspension system
- Minimum steering effort

DESIGN PROCEDURE

For the designing of the Steering System, a proper design methodology is followed. It involves the various steps which are discussed below:

- Identify key requirements.
- Selection of steering geometry
- Theoretical calculations by changing various parameters
- Checking of Ackermann percentage by four bar chain mechanism.
- Implementation

Designing of steering system is generally done in two phases:

Selection of Steering Geometry

Steering geometry decides the type of motion, with respect to each other between the different linkages and how they forward the motion given to them,

Generally, there are three types of Steering geometries.

- Ackermann geometry
- Anti-Ackermann geometry
- Davis geometry

Now a day, Ackermann and Anti-Ackermann is used because, they have no sliding pair in the linkages, thus increases its reliability and performance. Between Ackermann and Anti-Ackermann, depending upon the usage and design consideration, anyone can select.

Here, Ackerman steering geometry is selected because, it provides the common instantaneous center, during the cornering, thus preventing the slippage of the wheels.

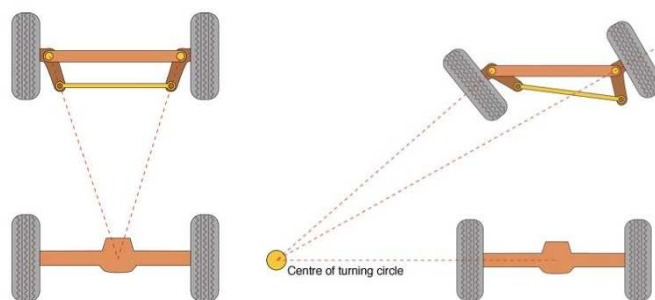


Figure 2: Ackermann Geometry

Finalizing the Performance Parameters

After deciding the Ackermann geometry, depending upon the usage of vehicle performance parameters for the vehicle, is selected.

- **Turning Radius** - The **turning radius** of a vehicle is the radius of the smallest circular turns (i.e. U-turn), that the vehicle is capable of making.
- **C Factor** – It indicates, for one rotation of pinion, how much the linear displacement in the rack is. It is given by the formula: C factor = Rack travel / one rotation of pinion
- **Lock to Lock Turn** - The steering wheel **lock to lock** can be described, as the number of **turns** it takes for a driver to get a fully turned wheel on one side, turned fully to the other side.
- **Steering Gear Ratio** - **Steering ratio** refers to the **ratio** between the turn of the **steering** wheel (in degrees) and the turn of the wheels (in degrees). Steering Gear Ratio = C factor/(Steering arm length/Pinion rotation)
- **Inner and Outer Angle** – These are the respective angles made by the front inner wheel and the outer wheel, during the turning.
- **Ackermann Percentage** – It numerically represents how much are the chances of the slippage in tires, during cornering. For 100% Ackermann geometry, there will be no theoretical slippage.

$$Ackerman = \tan^{-1} \left(\frac{wheelbase}{\frac{wheelbase}{\tan \delta_{outside}} - track_{front}} \right)$$

$$Ackerman_{percent} = \frac{\delta_{inside}}{Ackerman} \times 100$$

- **Steering Effort:** For any kind of vehicle driver, effort should be minimum & it depends on the steering gear ratio. If we have a large steering gear ratio, then it requires less driver effort. As we reduce the steering gear ratio, it increases the driver effort, to rotate the steering wheel and to compensate it; we have to increase the steering wheel diameter.

CALCULATIONS

Rack travel for one side (Z) = 3.75 cm

Dist. of trapezoidal mech. from wheel base (y) = 2.73 cm

Length of knuckle arm (r) = 8 cm

Wheel base (L) = 134 cm

Track width at front (T_f) = 125 cm

Track width at rear (T_r) = 115 cm

Distance between pivot point (t) = 115 cm

Knuckle arm angle (α) = $\tan^{-1} (t/2L)$

= $\tan^{-1} (115/2 \times 134)$

= 23.2°

Inner angle (Θ):

$$\sin (\alpha+ \Theta) = y+z/r$$

$$= 2.73+3.75/8$$

$$\alpha+ \Theta = \sin^{-1}(0.85)$$

$$\Theta = 35^{\circ}$$

Outer angle (ϕ):

$$\sin (\alpha- \phi) = y-z/r$$

$$=2.73-3.75/8$$

$$\alpha- \phi = \sin^{-1}(-0.12)$$

$$\phi = 30^{\circ}$$

Turning radius (R):

$$\text{For outer wheel (R}_o\text{)} = L / \sin (\phi) = 134/\sin(30.0^{\circ}) = 268 \text{ cm}$$

$$\text{For inner wheel (R}_i\text{)} = L / \sin (\Theta)$$

$$= 134 / \sin (35^{\circ})$$

$$= 234 \text{ cm}$$

Lock to lock turns: It is equal to the Steering gear ratio * average steering angle / 360°

It demonstrates the sensitivity of a steering wheel, at low to very low speed. The lesser the number of turns it takes, the more sensitive the steering wheel is. Sensitive steering wheels provide better responsiveness to steering inputs, even at high speeds and driving becomes almost instinctive.

At the same time, too much wheel sensitivity will make a car twitchy and hard to control. It's a very fine balance that carmakers have, to deal with.

OPTIMISATION

After deciding the performance parameter, steering system is designed in the software LOTUS SHARK v5.01, along with the Suspension System. During the modelling in software, a proper consideration should be given to two factors:

Wheel Alignment Angles

These are angles like camber, caster, king pin inclination etc., which decides the dynamic behaviour of the wheel geometry. Their combine effect also, provides the straight line stability and reversibility to the steering system. These values should be selected properly, depending upon the usage and performance of the vehicle.

Table 1: Wheel Alignment Values

S. No.	Parameters	Value
1.	Camber angle	0°
2.	Caster angle	2.43°
3.	King pin inclination	6.29°
4.	Scrub radius	46.42 mm
5.	Toe angle	0°

Steering Geometry Errors

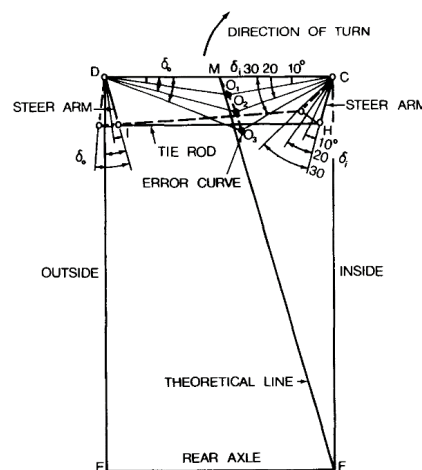
To perform as per the design consideration and expectation, there should not be any error, present in the steering system. The various types of major errors are discussed below:

Change in the Ackermann Percentage

Even after the initial design of 100% Ackermann Geometry, during the turning there is always change in the Ackermann percentage, during the rack travel or cornering. This leads to the slippage of tire and finally performance of vehicle decreases.

To confirm that, there should not be any change in the Ackermann percentage, a line is drawn from the midpoint of the Front axle, to the contact patch point of the Rear tire.

When the steering wheel is rotated, there are respective inner and outer angles, depending upon the rack travel. When these angle lines are extended rearward, as shown in Figure 3, they meet at a common point. This point should lay on the theoretical line of the 100% Ackermann percentage. If, the point lies on the line, then only in that case, there will be no change in the Ackermann percentage. Here, we have not considered the tie rod angles.

**Figure 3: Ackermann Percentage Error during Cornering**

Bump Steer

Bump steer is the term for the tendency of the wheel of a car, to steer as it moves upward or downward. The undesirable steering is caused by bump, in the track interacting with improper length or angle of suspension and steering linkages.

To reduce the bump steer, rack should be placed at correct height and length of tie rod should be optimum. Apart from that, inner ball joint of tie rod should be in the plane of the suspension mounting points, so that the suspension control

arms and tie rod will rotate about a common instantaneous centre.

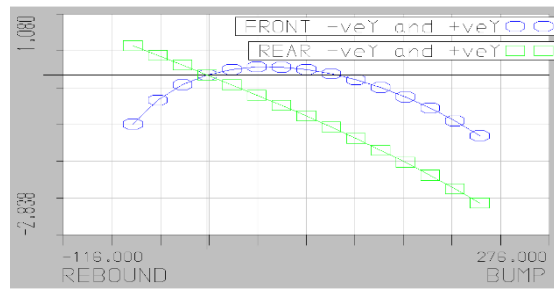


Figure 4: Toe Change during Bump

Roll Steer

During the rolling of the vehicle, there should not be any change in the steer angle of the wheel.

This prevents the further rolling of the vehicle and can be altered, by changing the location of inner and outer ball joint on the tie rod.

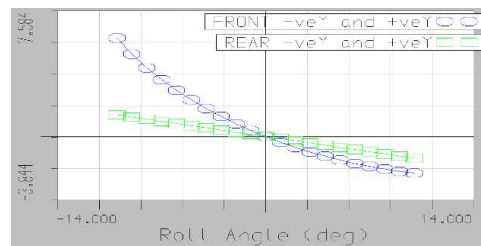


Figure 5: Toe Change during Rolling

Tuning with the Suspension system

The dynamic response of the vehicle, during cornering can be of the neutral steer, understeer or oversteer. This curvature response of the vehicle depends upon the location of the Neutral Steer Point (NSP). It is the point at which, the lateral forces acts on the vehicle

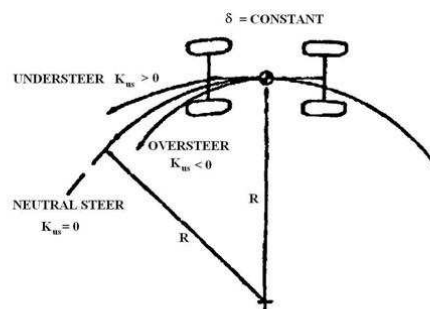


Figure 6: Vehicle Response during Cornering

If the NSP coincides with the C.G of the vehicle, then the response will be Neutral steer. However, if it is behind the C.G, then the vehicle will be over steer and vice-versa.

$$l_N = -\frac{l_f K_f - l_r K_r}{K_f + K_r}$$

NSP is in front of the center of gravity, when $l_f K_f - l_r K_r$ is positive, this leads to the greater slip angle at the Front Axle, leading to under steer and when $l_f K_f - l_r K_r$ is negative, it is behind the center of gravity & this leads to greater slip angle, at the Rear Axle leading to the Over steer. When $l_f K_f - l_r K_r = 0$, the NSP coincides with the centre of gravity and vehicle response is Neutral steer.

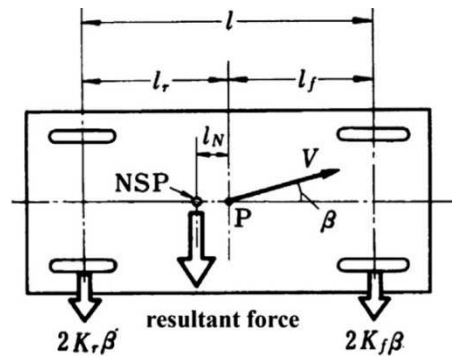


Figure 7: Forces Acting on the Vehicle during Cornering

Thus, by changing the stiffness of the Front and Rear suspension, the response of the vehicle can be changed, as per requirement.

RESULT AND CONCLUSIONS

Following the above mentioned design procedure; there is a significant increase in the performance and stability of the vehicle. This design procedure is followed, to design the steering system of the BAJA SAE INDIA 2017 ATV vehicle.

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